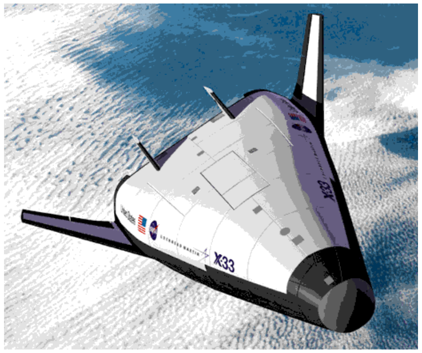
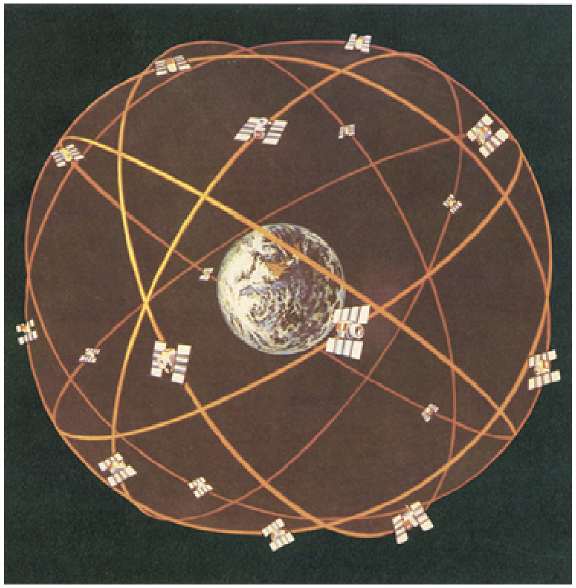
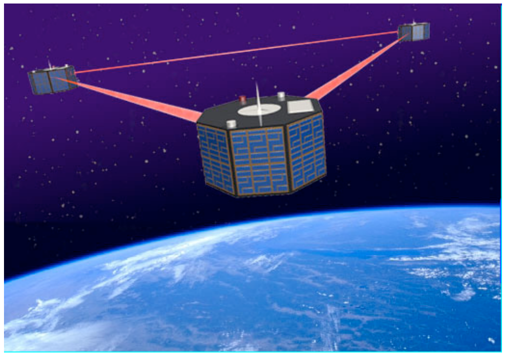


The Global Differential GPS System

Yoaz Bar-Sever/JPL

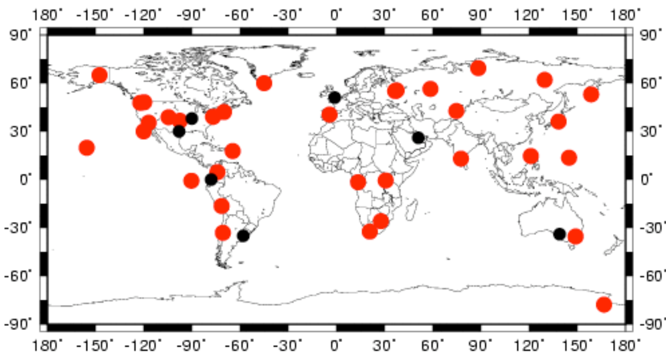
Yoaz.Bar-Sever@jpl.nasa.gov





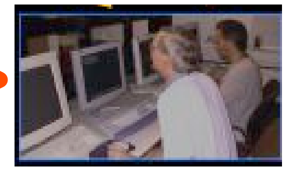
JPL's Global Differential GPS System

Global real time network



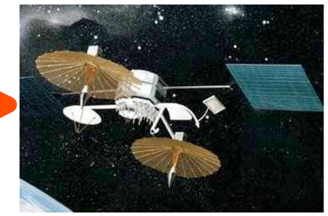
Internet

JPL GDGPS Operations Center



Uplink

TDRSS



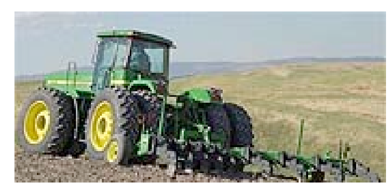
Internet

Broadcast

Revolutionary new capability:

decimeter real time positioning, anywhere, anytime

Remote users



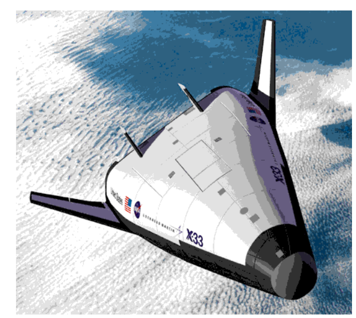
For more info see:
http://galia.igdg.net/igdg

Specific Benefits

Enable precision Interferometric SAR without crosslink metrology
- 0.1 nsec synchronization across arbitrarily large formations
- Bistatic SAR monitoring of currents and river flow
- Real time monitoring and assessment of natural hazards
- Reconfigurable and repairable radar apertures

Enable precision orbit control
- 10 cm repeat path accuracy from air and space
- Provides GPS integrity for autonomously controlled satellites

Improved Earth system forecasting capabilities
- Improved weather forecasting and tactical oceanography by lowering latency of Geophysical Data Records (GDRs) from altimetric satellites and GPS occultation constellations

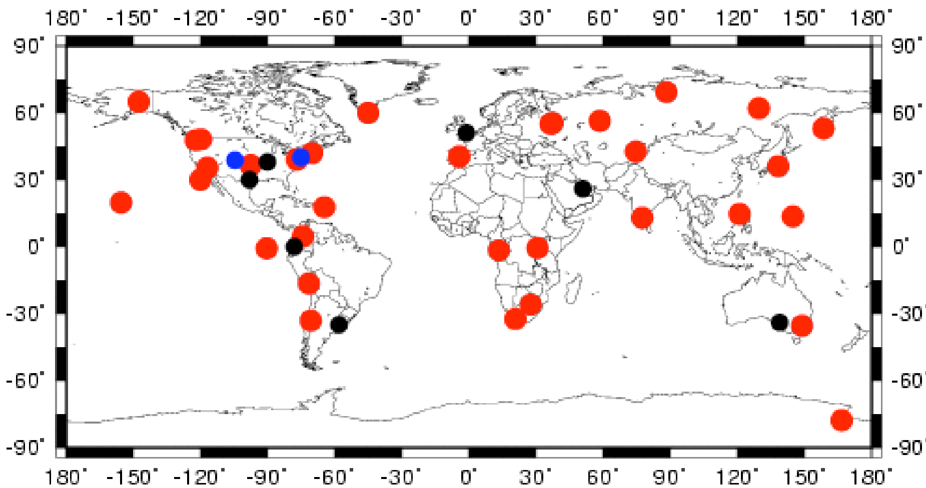


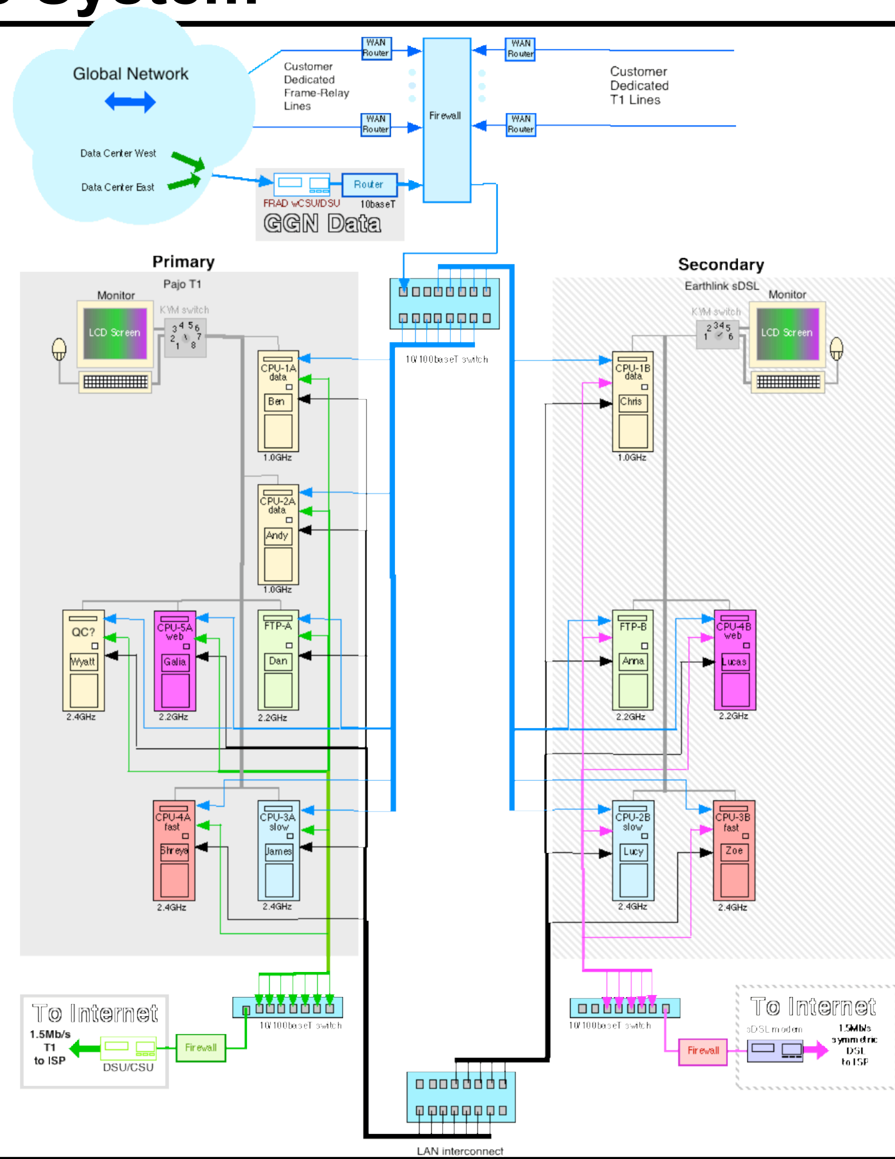
Next generation shuttle/RLV/Space Plane
- cm-level autonomous proximity operations
- Safe autonomous landing anywhere in the world
- Proposed JPL/MSFC TCMIG navigation payload is based on GDGPS

Many civil and national security applications

Mature and Reliable Ground Operations System

- Reliability through redundancy: **No single points of failure**
- Automatic fault detection and data rerouting
- Continuous Web monitoring in the public domain
- **99.99% reliability since 2000**

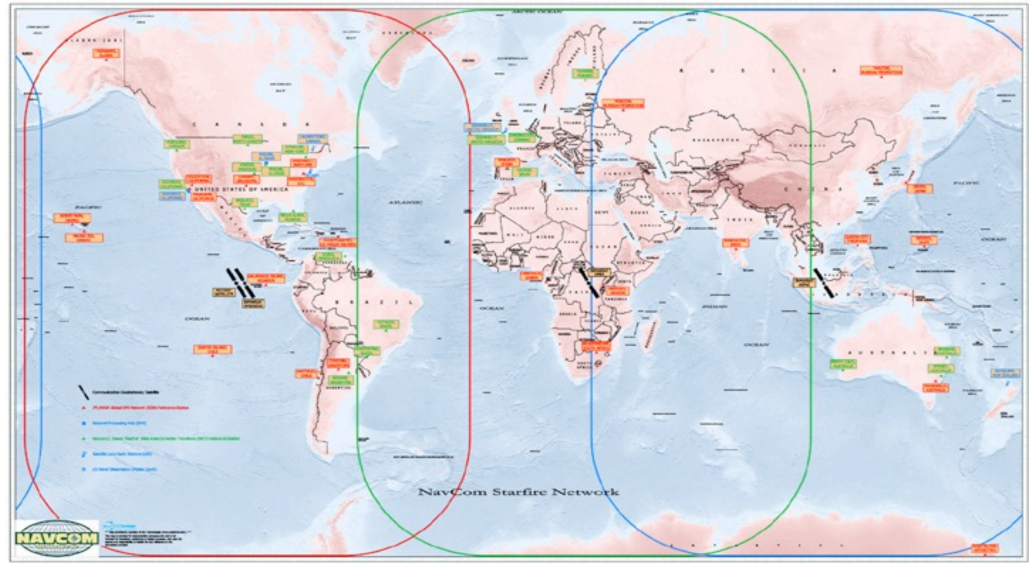


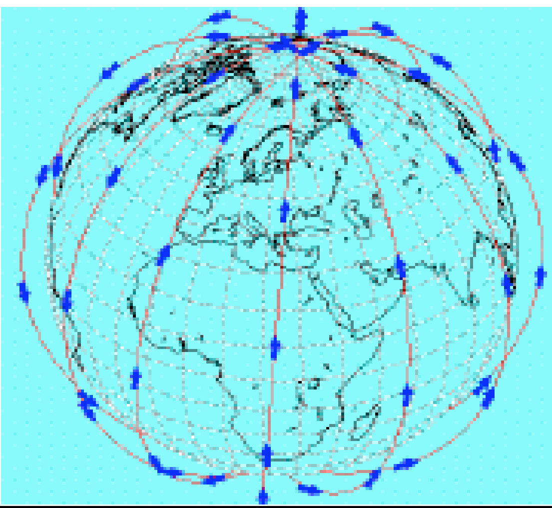


Communication Relay Systems

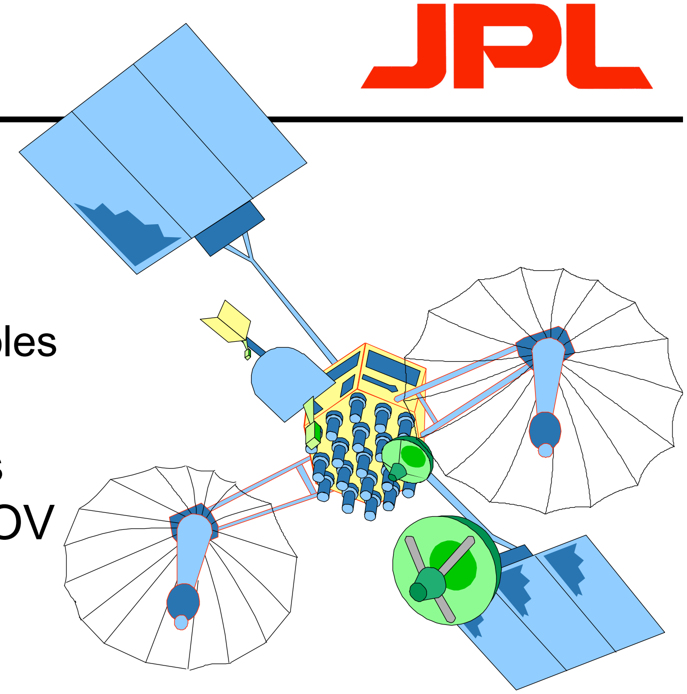
True global reach:

- The open internet
- 3 Inmarsat satellites with global coverage up to latitude ±75º (operated by Navcom
- Iridium telephone modems provide internet access globally (including the polar regions)
- Future TDRSS broadcast

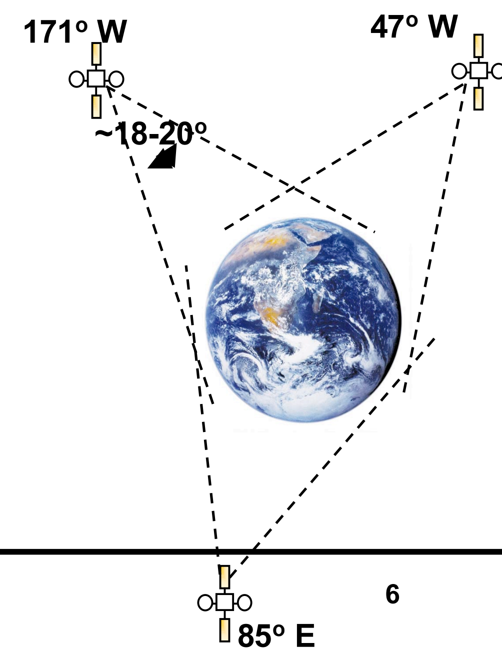




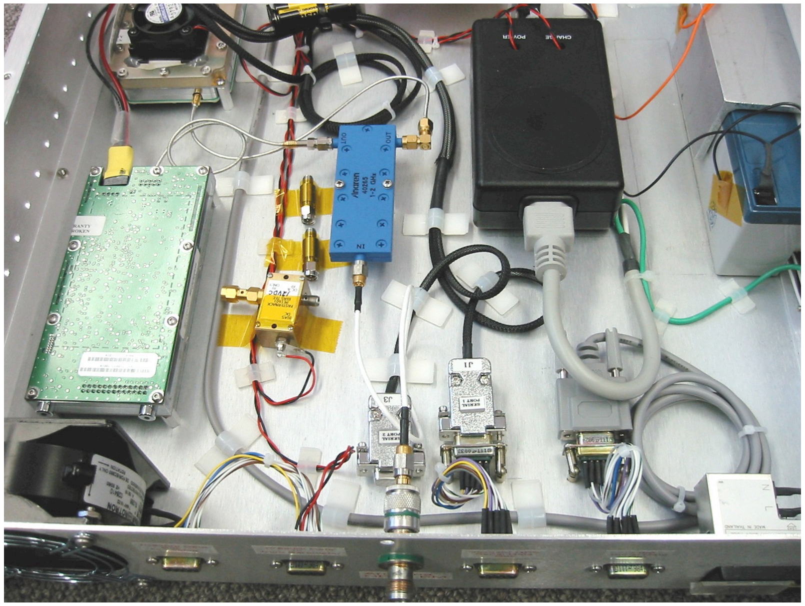
New TDRSS Service: GDGPS Broadcast



- New global beam designed
  - Element phasing controlled via upload commands
  - Fixed beam ~ ± 9 - 10 ^{o} ; covers altitudes to ~ 1000 km
  - Worst case link margin: 3 dB at 1000 km over over the poles
    20 dB over the equator
- 24 x 7 S-band MA broadcast from each TDRS provides continuous GDGPS correction data to all LEO s/c in FOV
- MA broadcast baseline
  - PN code modulated / BPSK data stream
  - Unique PN code per TDRS
  - 400 bps data rate including rate 1/2 FEC for 1 Hz GDGPS corrections
- Next Generation TDRSS will be more capable
  - Wider beam for better polar coverage
  - Stronger signal
- Initial ground tests in FY03; funded by Code M



Airborne Demonstrations



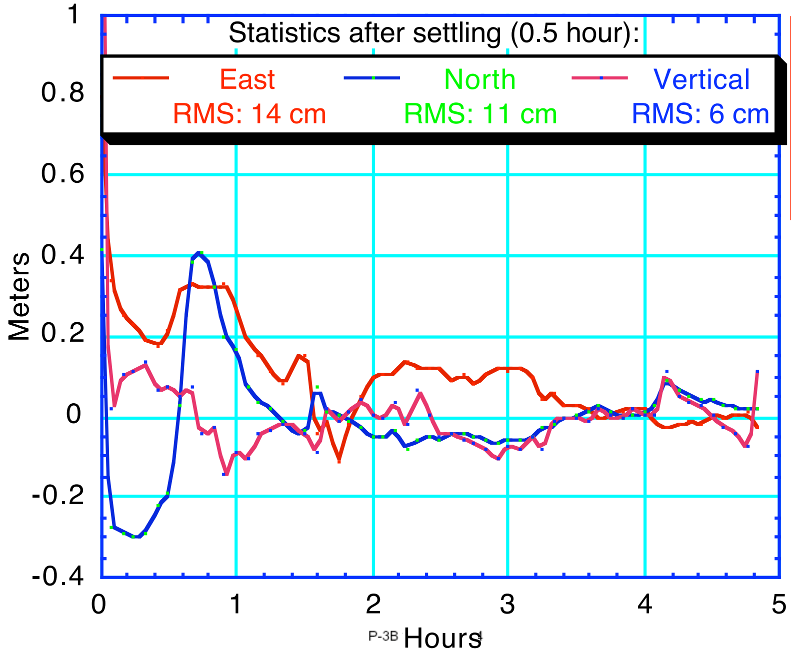
Extensive flight tests

- North America, February - September 2002: NASA DC-8 AirSAR
- Greenland, May 2002: NASA P-3 LIDAR
- Sweden, polar region, February 03: NASA DC-8

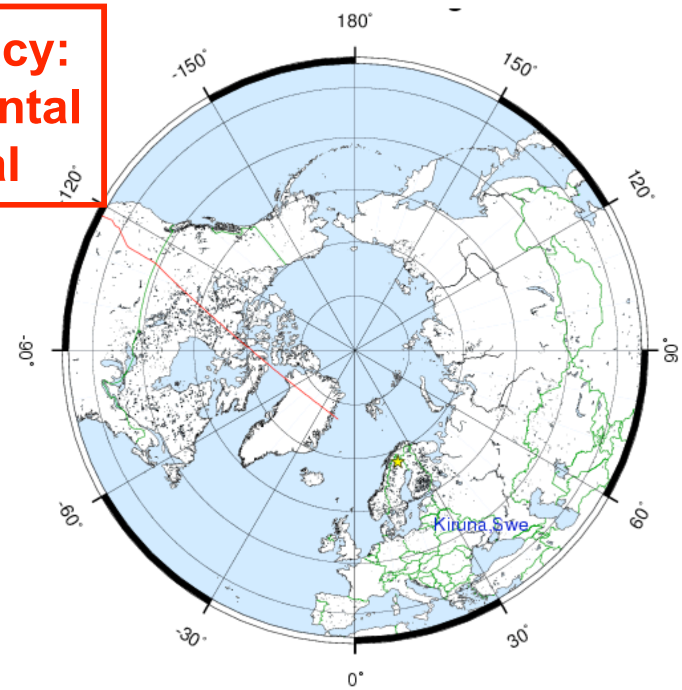
Performance validation by comparisons with:

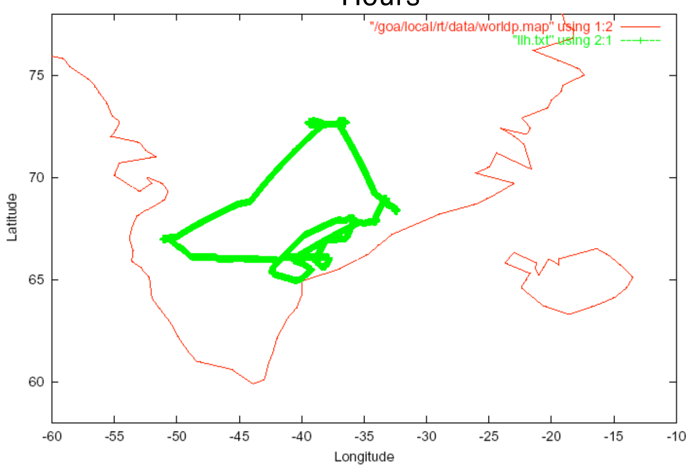
- Post processing (precise orbits + smoothing)
- Independent local area differential techniques
- Laser ranging

Airborne Demonstraions (cont.)



Consistent Accuracy:
10 cm RMS Horizontal
20 cm RMS Vertical





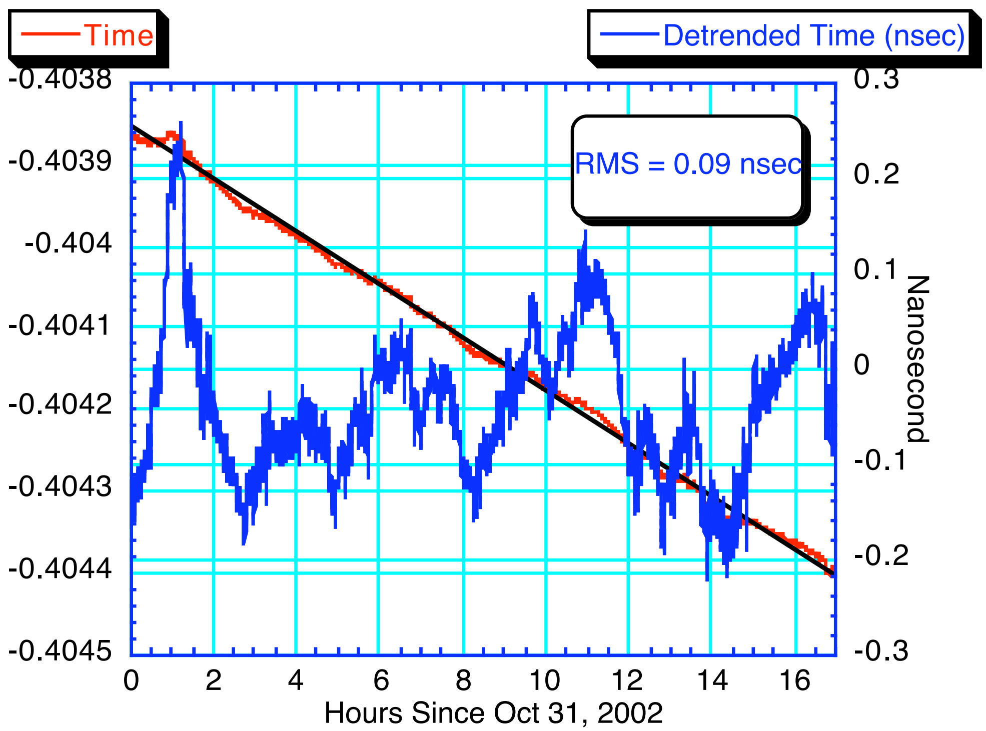
Difference between GDGPS and LADGPS (cm)

Date	East	North	Vert
31 May	17.2	10.1	13.0
02 Jun	4.5	4.6	5.9
04 Jun	8.0	6.1	12.6

Time Transfer Capabilities

Real-Time time transfer accuracy is consistent with that of positioning:
nanosec level for dynamic platforms; 0.1 nanosec level for static platforms

Time Transfer from USNO to JPL Maser
Position held fixed



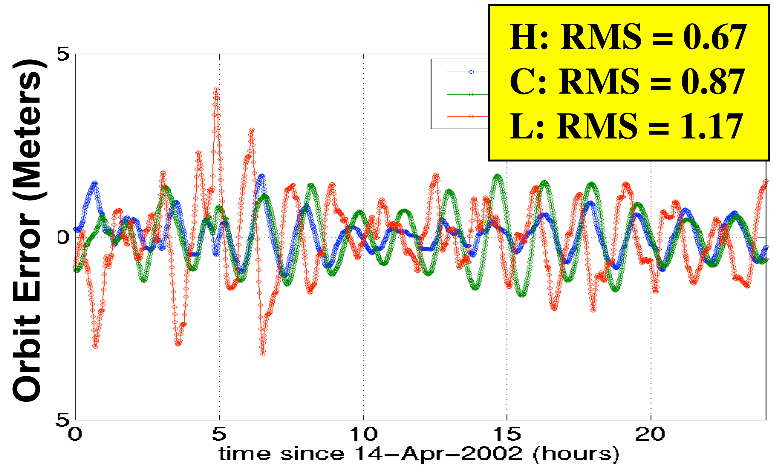
An order of magnitude improvement compared to unaided GPS

Orbit Determinations Demonstrations

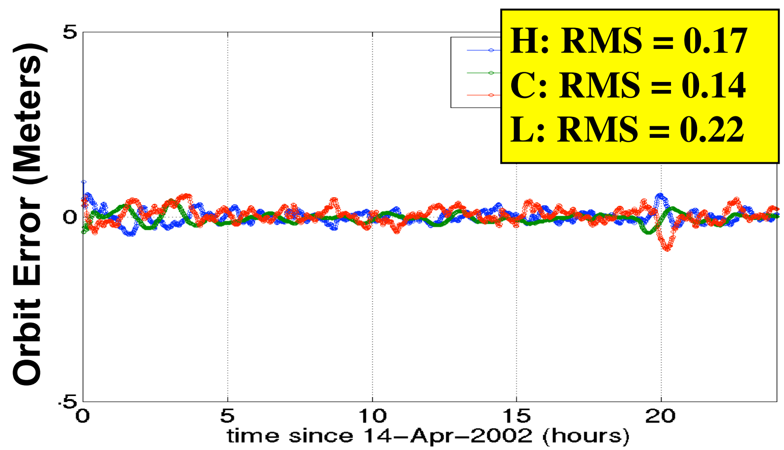
Assess end-to-end system performance of precise real time orbit determination

- In-space tests of software onboard SAC-C (but without GDGPS correction data)
- GDGPS performance “simulated” with ***real data, real orbits, real time filter***

Altitude: 650 km



This is how well we currently perform onboard SAC-C (w/o GDGPS corrections)



This is how well we expect to perform when the complete differential GPS receiver is deployed on a future SAC-C-like s/c

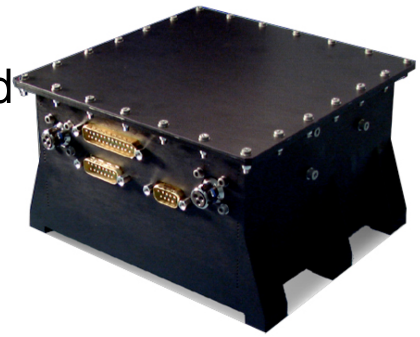
Results for better modeled satellites:
CHAMP: **20 cm** 3D RMS
Jason-1: **10 cm** 3D RMS
2.5 cm Radial
(science quality)

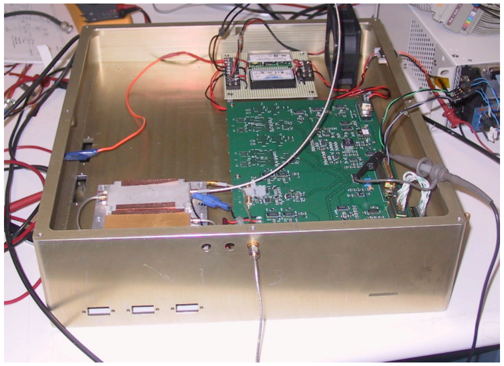
Spaceborne Global Differential GPS Receiver

Hardware approach: flexible configuration that can be adopted to a variety of flight opportunities and risk postures

- A two-box configuration comprising of a BlackJack GPS receiver and a differential receiver/processor with S-band front-end and GDGPS software
  - Differential receiver is based on the Autonomous Formation Flyer baseband processor board
  - Fully reconfigurable FPGA; PowerPC 750

- A single box comprising of Blackjack GPS receiver, augmented with S-band front end and GDGPS software





Developed prototype spaceborne differential GPS receiver for precise real time orbit determination and time transfer

Development status:

- Completed design, fabrication, and assembly of a prototype differential receiver
- Receiver undergoing testing

The Need for Flight Validation

Payload cannot be adequately tested on the ground

- No hardware-in-the-loop simulators capable of decimeter level accuracy
- No hardware-in-the-loop simulators for combined GPS and GDGPS corrections

Orbital environment provides unique challenges

- Due to occultation of signal in troposphere and ionosphere
- Different Doppler signature
- Lower SNR
- TDRSS switchover

=> Flight validation is necessary to retire risk for first operational use

Flight Opportunities

Goal: Identify missions of opportunity to host the GDGPS receiver

	NASA	DoD/OGA	Foreign Collaboration
2004			
2005		MLV-5	
2006	**NPP**		EQUARS
2007	**OSTM*, OCO**	LDCM	SAOCOM
2008	**GPM**, AQUARIUS, Ocean Vector Winds		
2009	**Restless Planet***		

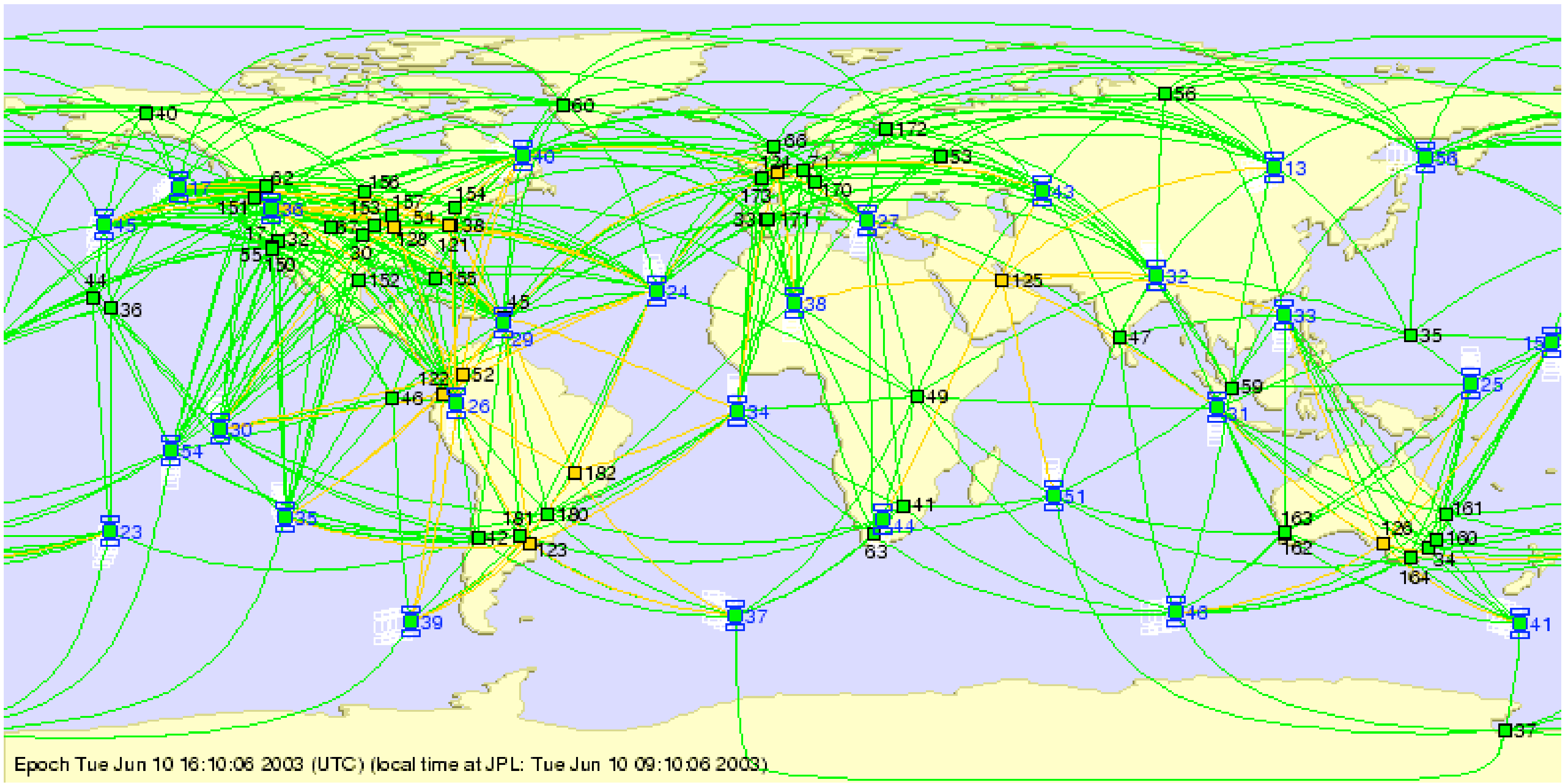
* Mission enhancing

In bold: strong prospects; positive initial contact

GPS Integrity Monitoring

GDGPS is the only redundant real time network observing all GPS satellites all the time

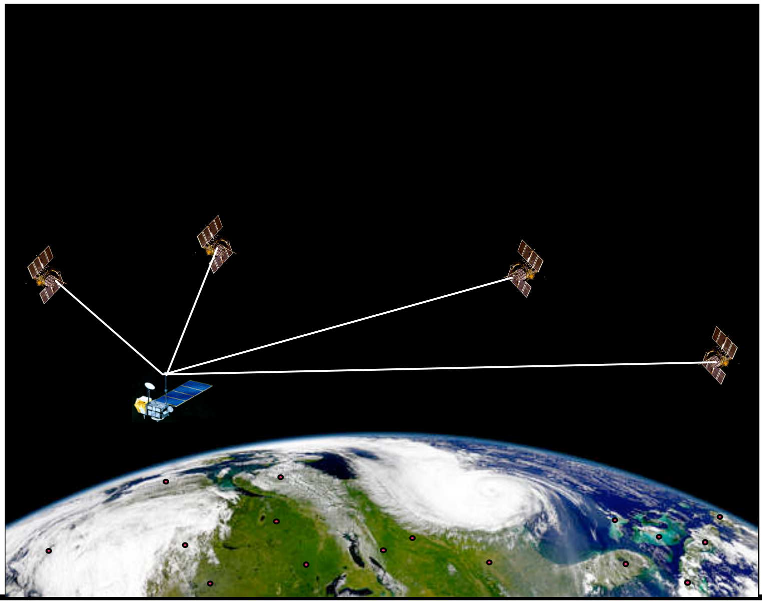
State-space approach enables separate monitoring of clocks and orbit states

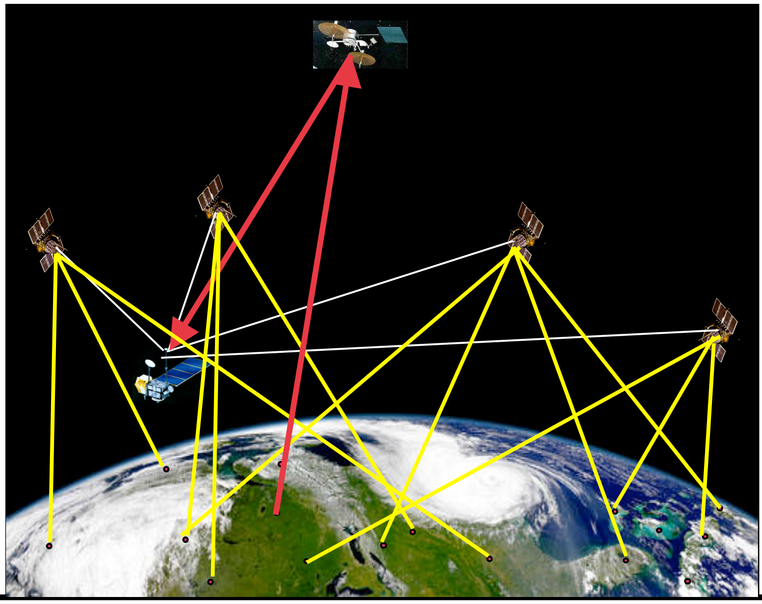


Revolutionary New Capabilities

The NASA Global Differential GPS (GDGPS) system provides spacecraft with revolutionary new capabilities for real-time orbit determination and time-transfer

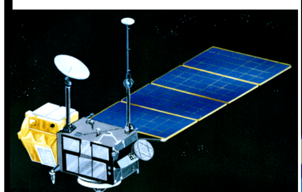
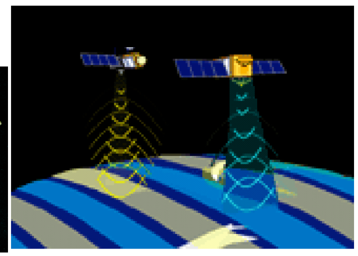
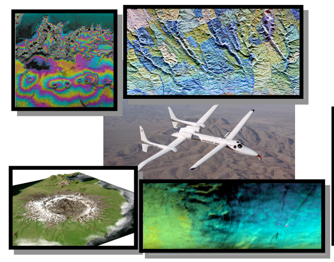
	State of the Art (unaugmented GPS)	GDGPS	The Next Step: GDGPS+IMU+Optical
Real-time orbit determination	Few meters	0.1 - 0.3 m	**0.01 m**
Real-time time-transfer	~10 nsec	0.1 nsec	**< 0.1 nsec**
Integrity **(GPS malfunction flags)**	Not available	Included	**Included**

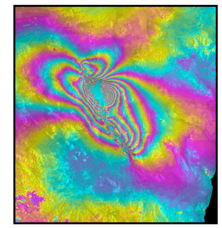
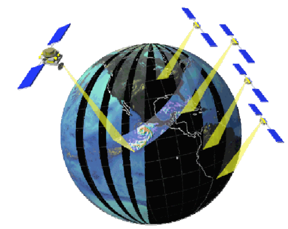




Roadmap to Autonomy and Reduced Latency

Goals	Reduce latency of science products	Real-time Earth monitoring; Autonomous spacecraft operations; Decimeter accuracy of real-time science products	Natural hazard forecasting and monitoring; constellations for weather and remote sensing; Centimeter accuracy of real-time science products

mission concept	Near real time processing on the ground with real-time GPS orbits	Onboard real-time position knowledge and control; Onboard science processing; Repeat pass interferometry	Coordinated measurements and constellation sensor autonomy; real-time precision formation flying; distributed data processing; L-band InSAR
New system architecture & technologies	Ground processing with NASA's Global Differential GPS System	Global Differential GPS receiver and software for onboard positioning and timing TDRSS GDGPS service	GDGPS/accelerometer/star-tracker integrated receiver; Constellation Communications and Navigation Transceiver Reconfigurable radar; Radar arrays

Increasing Science Capability and Time